NASA Technical Memorandum 84905

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SUMMARY

This document discusses the development of the Dryden Flight Research Facility Battery Systems Laboratory. This laboratory processes nickel-cadmium and silver-zinc batteries used in the various flight research vehicles flown at the Dryden facility. Described is the evolvement of the original manually operated lead-acid battery facility to the present computerized laboratory. Described also are the equipment and present capabilities of the laboratory, which can process both sealed and wet vented cells that range in capacity from 0.5 to 200 A-hr.

INTRODUCTION

In July 1964, a United Airlines Viscount suffered a fire in the cabin area and crashed near Parrotsville, Tennessee. In August 1971, an Aloha Airlines Viscount caught fire on landing at Honolulu. Between the time that the control locks were engaged during the landing run and the fire was extinguished (approximately 4 min) the flying-control rods had melted away at a point where they passed over the left battery, which had been the source of the fire (ref. 1). Both fires were attributed to nickel-cadmium battery thermal runaway problems. (Battery terminology is defined in refs. 2 and 3.)

Each vehicle undergoing flight tests at Dryden requires the use of high-energy-density, low-weight, constant-voltage-profile batteries to provide emergency power in the event of primary power source failures. Research vehicles such as the M2, HL-10, and X-24 (forerunners to the space shuttle) used batteries as their primary power source.

Research flight tests require batteries that will not fail. Dryden's Battery Systems Laboratory was established to perfect maintenance techniques required to guarantee safe, dependable batteries, to supply the batteries needed to support the flight research program, and to prevent battery thermal runaway conditions.

EARLY BATTERY FACILITY

Prior to 1965, Dryden's battery facility consisted of a 2.7- by 6.1-m (9- by 20-ft) metal shed that housed a single industrial lead-acid battery charger. This charger was used to charge lead-acid and nickel-cadmium batteries. The few nickel-cadmium batteries were used as emergency batteries for F-104 vehicles. Both battery types were processed in the same room and were maintained by a single technician. Because of the constant failures of the nickel-cadmium batteries, additional batteries had to be charged and ready for flight support at all times.

The introduction of the Lunar Landing Research Vehicle (LLRV) in 1964 also introduced the silver-zinc rechargeable battery, which was used as emergency 28-V dc power in the event of a failure of the LLRV's 28-V dc generator. Lead-acid battery maintenance techniques were used to service the battery, but this resulted in poor battery performance. Because of this poor performance, the silver-zinc battery was rejected by the project and replaced with a higher-capacity nickel-cadmium battery already being maintained by the Dryden facility.

M2/HL-10 Batteries

In 1966, a series of vehicles called lifting bodies began flying at Dryden. Even though Dryden had rejected the silver-zinc battery for use in the LLRV, it was chosen for the lifting body program because of its flat discharge voltage profile (fig. 1) and because its energy density (watthours per unit weight) is approximately four times that of the more familiar nickel-cadmium battery. The M2 and HL-10 used six batteries manufactured by the Yardney Electric Corporation. These batteries consisted of both high- and low-rate types and could supply currents up to 240 A without damage to the cells. Twelve of these batteries had to be maintained to support the M2 and HL-10 program.

With the number of silver-zinc batteries increasing, along with the nickel-cadmium batteries already on hand, the battery facility had to be expanded. Both the nickel-cadmium and silver-zinc batteries use potassium hydroxide as the electrolyte, whereas the lead-acid battery uses sulfuric acid as the electrolyte. Because one electrolyte is a strong base and the other is an acid, contamination became a potential hazard, and the decision was made to separate the servicing areas. Since the lead-acid batteries were used mainly in ground vehicles, the service area for these units was moved and made the responsibility of garage personnel.

Modified constant-potential chargers were acquired to charge all of the silver-zinc batteries simultaneously. Servicing the Yardney silver-zinc batteries was a simple task. The chargers monitored the overall voltage level of the battery, and when the voltage of the battery reached a manually set voltage limit, the chargers automatically stopped the charging process. This method of charging worked well because of the conservative rating of the Yardney batteries. Cell imbalance was not a problem, and simple charging techniques could obtain acceptable results.

X-24 Batteries

The X-24 lifting body research vehicle project introduced another series of silver-zinc batteries, supplied by ESB Company. The internal construction of the cells made it difficult for the cells to be properly wetted during the cell activation phase, and dry spots formed within the cells. Capacity imbalance was prevalent because of this activation problem, and tighter monitoring controls had to be maintained during both charge and discharge operations.

Charging techniques that were used for the Yardney cells were applied to the ESB cells, and the same Yardney chargers used to process the M2 and HL-10 batteries were used to charge the X-24 batteries. Because of cell imbalance in the ESB cells, several cells experienced overcharge, resulting in two batteries' exploding during one of the charge cycles. To prevent such incidents from recurring, two 12-hr shifts were instituted with two technicians working each shift. Each cell was checked at 5-min intervals when the battery approached the fully charged status. The X-24 vehicle required eight batteries to be maintained by the facility; 160 cells had to be monitored manually during the charge cycle.

Load testing of the batteries also proved to be a task requiring careful monitoring. During load test operations, a set of batteries was destroyed because of excessive heat and electrolyte leakage.

As the flight schedule for the X-24 vehicle became more intense, the task of manually monitoring the batteries became excessive and expensive.

Increased Use of Nickel-Cadmium Batteries

While the silver-zinc battery service requirements were expanding, the nickel-cadmium battery use also increased. Additional research vehicles, such as the F-111, JetStar, Aero Commander, F-8, PA-30, and additional F-104s, and ground support equipment were added to the nickel-cadmium battery support requirements.

BATTERY SYSTEMS LABORATORY

Computerized Monitoring System: Laboratory Installation and Expansion

Servicing the nickel-cadmium batteries in a way to deliver dependable power was a main concern as failures became prevalent during this expansion period. Because of the increased number of batteries being used, the monitoring task for the silver-zinc batteries became too much to handle manually. Two goals were thus defined for the battery laboratory: (1) develop a computerized system to maintain silver-zinc batteries, and (2) develop maintenance techniques to ensure dependable nickel-cadmium battery performance.

In April 1970, a 200-channel, low-speed, analog scanning system was installed. This system used the Hewlett-Packard 2115B minicomputer as the system controller. The function of the initial system was to make the necessary scans required to monitor each cell in the batteries used for the X-24 vehicle. The HL-10/M2 batteries would still be charged manually. Eight Yardney chargers were modified to permit computer control for X-24 battery charging. In addition, a technique had to be developed to permit quick attachment of the battery to the monitoring system. Dryden designed spring-loaded monitoring plates to perform this task (figs. 2 and 3).

This early system (fig. 4) consisted of the following components: (1) 200-channel cross-bar scanner, (2) digital voltmeter, (3) ASR 33 teleprinter, (4) 500-character/sec optical tape reader, (5) 120-character/sec paper tape punch, (6) eight modified Yardney silver-zinc chargers, and (7) 2115A computer (16K bytes random access memory (RAM). The initial system, though limited in performance, permitted continuous monitoring.

The success of the early system led to the following modifications in 1973: (1) expansion to 800 channels, (2) replacement of the 2115A computer with a 2116B computer containing 32K bytes of RAM, (3) addition of a 200-line/min line printer, (4) modification for computer control of 23 Yardney silver-zinc battery chargers, (5) modification of five Sun Electric Company 0- to 300-A load banks to permit computer-controlled simulated-flight electrical-load tests, and (6) addition of a moving-head cartridge disk system for program storage (fig. 5).

The laboratory was also expanded into larger quarters with a separation of work activity (figs. 6 and 7), as follows:

1. Battery processing area: temperature-controlled room for performing charging and discharging functions.

2. Battery-assembly/tear-down area: Room in which technicians build up new batteries, reassemble batteries ready to be issued, and tear down and inspect batteries from flight.

3. Computer/office area: Computer room housing all computer and peripheral devices.

The expanded computer system permitted the automatic monitoring of 800 analog signals and the on-off control of 32 independent devices. This number of channels permitted simultaneous monitoring of batteries for all of the lifting body vehicles being flown at Dryden. The sample rate of the system was sufficient to permit monitoring all 800 channels at 2-min intervals, and more than enough time to detect preset cell limit levels and respond appropriately. Use of the discrete on-off functions supplied by the computer-controlled relays enabled electrical loads to be automatically applied and removed. This process permitted the verification of battery performance by simulating the electrical loads the vehicle would encounter during flight. Results of the load tests and charging operations were listed on the system line printer for analysis during the task or were available for evaluation after the test. Since silver-zinc cells will not tolerate sustained overcharging, software was written to protect the batteries if the scanner/voltmeter system did not respond to the scan command within 1 min.

Nickel-Cadmium Battery Area Changes

While the computer system was being installed in the silver-zinc battery area, newer, higher-performance charger/analyzers were being installed in the nickel-cadmium battery area. Typical constant-current charging methods require 7 hr to recharge the type of vented wet cells used at Dryden. Newly designed Christie ReFlex pulse charger/analyzers were acquired, as were pulse charger/analyzers from the Marathon Battery Company. The ReFlex chargers permitted a battery to be at rated capacity within 1 hr, and Marathon chargers permitted a battery to be recharged within 4 hr. Both types of chargers had built-in load banks, permitting capacity tests to be conducted without moving the battery (fig. 8).

Tighter manual monitoring of cells during charge and discharge cycles was also instituted. Temperature checks of the cells during the charge/discharge operations were made and any battery over temperature was removed from the process cycle and permitted to cool. Vent caps were kept clean throughout the charge cycle, and any cell spewing electrolyte was checked. Each cell in the battery was checked for cell balance, and all low-voltage cells were replaced. The tighter monitoring of the cells and the additional chargers eliminated the reliability problems.

PRESENT LABORATORY CAPABILITIES

Computer System

From April 1979 to September 1982, a Real-Time Executive (RTE) Multitask Operating System was installed in the laboratory. This system is based on the Hewlett-Packard 1000, Model 40, RTE computer system and uses Neff Instrument Corporation multiplex hardware to receive the voltage signals from the battery cells and chargers (figs. 8 and 9). The computer system is wired to monitor and control 40 chargers with batteries containing 1 to 24 cells connected in a series. It runs continuously and is capable of scanning up to 1000 samples/sec. If a hardware failure occurs, a notice appears on the system printer to alert the operator (fig. 10). A list of present laboratory equipment (fig. 11) is found in the appendix. Figures 12 and 13 show the computer system and the silver-zinc battery charging areas, respectively.

Through computer terminals located in the battery processing area the technician can perform the following tasks:

1. Computer-directed simulated-flight electrical-load tests. These tests are used to quickly determine the condition of a battery by applying the amount of electrical load the battery will experience in flight. This test is performed each time a battery is issued from the laboratory to be installed in a vehicle.

2. Capacity tests. These tests are performed on a calendar schedule. In this process, the battery is fully charged, then discharged at its 1-hr ampere rate until an end-of-discharge voltage level is reached. This test is used as an indication of the total health of the battery (fig. 14).

3. List data functions. Throughout any battery operation, charge or discharge, the operator may obtain a display or a hard copy of the voltage reading of any cell along with the amperes being used (load tests) or amperes being accepted (charging) (fig. 15). A status report showing which chargers are active can also be displayed (fig. 16).

The computer system automatically schedules the battery scan program to run every 2 min. Any cell indicating either a charge-cell condition or an out-of-tolerance condition will cause a shutdown of the charger to occur. The shutdown readings and the reason for shutdown will be listed on the system printer (figs. 17 and 18).

Nickel-Cadmium Battery Servicing Capabilities

The nickel-cadmium battery area has the following equipment:

1. Two 200-A Christie ReFlex charger/analyzers

2. Six 80-A Christie ReFlex charger/analyzers

3. Three Marathon PCA-131 nickel-cadmium charger/analyzers

4. One Dryden-designed 0- to 1-A, 1- to 24-cell constant-current charger/analyzer

The Neff scanning system has been wired to permit the nickel-cadmium batteries to be monitored with the silver-zinc batteries. Cabling has also been installed to permit the nickel-cadmium charger/analyzers to be shut down by computer command. The charger/analyzers must be modified to accept these signals.

The laboratory also has a cold chamber (2.2 m (7.2 ft) high, 2.3 m (7.4 ft) wide, 0.6 m (2 ft) deep) capable of subjecting batteries to temperatures ranging from room temperature to 0° C (32° F) and a 24-channel temperature recorder with relay contacts is available for temperature control of charging/discharging operations.

CONCLUDING REMARKS

Since 1963, Dryden has been actively engaged in developing techniques for maintaining batteries used in research vehicles at the facility. Over the years, several important factors for successful battery operation have been derived. These findings are listed below.

Discharging

The only means of determining the health of nickel-cadmium and silver-zinc batteries is to perform a capacity test. More information can be determined about the battery under load when it is tested at its 1-hr discharge rate than by testing it at its 2- or 5-hr discharge rate. Many batteries tested successfully passed the 2-hr discharge capacity tests, yet failed when they were installed in the aircraft and subjected to the actual aircraft electrical loads. Because of this difference in battery performance, all batteries used for flights are capacity-tested at their 1-hr rate.

To prevent the battery from being damaged during discharge tests, battery voltages must be constantly monitored. It is not sufficient to monitor only the overall voltage of the battery. Each cell must be monitored in the event that a low-capacity cell exists in the battery.

The temperature of the battery during discharge affects the useful life of the battery cells. Overheating the cells can damage the separator material used inside the cell. Damaged separators can cause internal shorts to develop within the cell. Excessive temperature can also cause the plastic cell cases to become soft, warping the cell sufficiently to cause permanent damage to the cell structure and rendering the cell unusable for flight. Batteries must therefore be monitored throughout any discharge cycle, and testing must be stopped whenever the temperature of the battery rises to the danger point.

Each battery used at Dryden is subjected to a load test before being issued. The load test is based on the actual load the battery will encounter while it is installed in the vehicle. Each cell is monitored during this test, and any cell not meeting the preestablished limits will cause the test to stop. The rejected battery is further tested to ascertain the reasons for the rejection. Any cells that cannot be brought up to specifications are discarded.

Charging

When charging nickel-cadmium or silver-zinc cells, the manufacturer's instructions are followed. In addition to the manufacturer's procedures, the following procedures are also used.

1. Each cell is monitored for voltage.

2. The charging process on the silver-zinc units is stopped when any cell reaches the end-of-charge voltage level.

3. If the pulse or ReFlex pulse chargers are not available for vented wet-cell nickel-cadmium batteries, the constant-current method is used for charging.

If a constant-current charger is not available and a constant-potential charger must be used, the battery is monitored for temperature rise, voltage drop, and current rise, which would indicate a thermal runaway problem. Should this condition be detected, charging is stopped at once.

General Care of Batteries

Proper performance of the battery can be expected only if the battery cells are kept as clean as possible. Deposits resulting from electrolyte leakage or battery fumes must not be permitted to collect on battery terminals, cases, or interconnecting straps.

Any voltage between battery case and cell terminals must be eliminated; such a voltage can be an indication of a leaking, defective cell. All cells leaking because of structural defects must be removed from flight status.

The water level in a charged nickel-cadmium cell must be checked. If the level is low, only distilled or demineralized water should be used to bring it up to the proper level.

All nuts and bolts used with interconnecting straps and battery terminals must be checked and maintained at the proper torque, while the battery is being charged or discharged.

Ames Research Center
Dryden Flight Research Facility
National Aeronautics and Space Administration
Edwards, Calif., February 2, 1983

APPENDIX — PRESENT BATTERY SYSTEMS LABORATORY EQUIPMENT

1. Twenty-two Yardney 24-cell, 10-A modified constant-potential chargers

2. Three Versatronics 0- to 20-A, 1- to 60-V constant-current charger/analyzers

3. Five Sun Electric 0- to 300-A load banks (items 1, 2, and 3 can be operated manually or by the computer system)

4. One RTE system consisting of the following items:

   a. HP1000, Model 40, computer system (2113B minicomputer with 512K-byte RAM)

   b. HP7906, 19.6M-byte cartridge disk system

   c. HP2645 display station with dual minicartridge tape system

   d. Sixty-four channels of on-off relay output

   e. 180-character/sec dot matrix printer

   f. 500-character/sec optical tape reader

   g. 75-character/sec heavy-duty tape punch (punches paper or mylar)

   h. Three remote CRT terminals (expandable) (one terminal tied by telephone line to programmer's office at remote location in another building)

   i. Neff series 620 system using Neff series 400 multiplexers to provide 1024 channels of analog input (multiplexer interfaced to the Hewlett-Packard system through a Neff series 500 controller). The channels provide 96 channels of low-level input (input sensitivities ±5 mV to ±10 V) and 928 channels of high-level input (input signals up to ±50 V).

REFERENCES

1. Nickel-cadmium batteries — the runaway risk. Flight International, Sept. 26, 1972, p. 416.

2. Pipal, F. B.; Carr, Charles; Grun, Charles; and Sulkes, Martin: Batteries. Machine Design, April 11, 1963.

3. Marathon Battery Instruction Manual. Ba-89, Rev. 578, Marathon Battery Company, Waco, Texas, 1978.

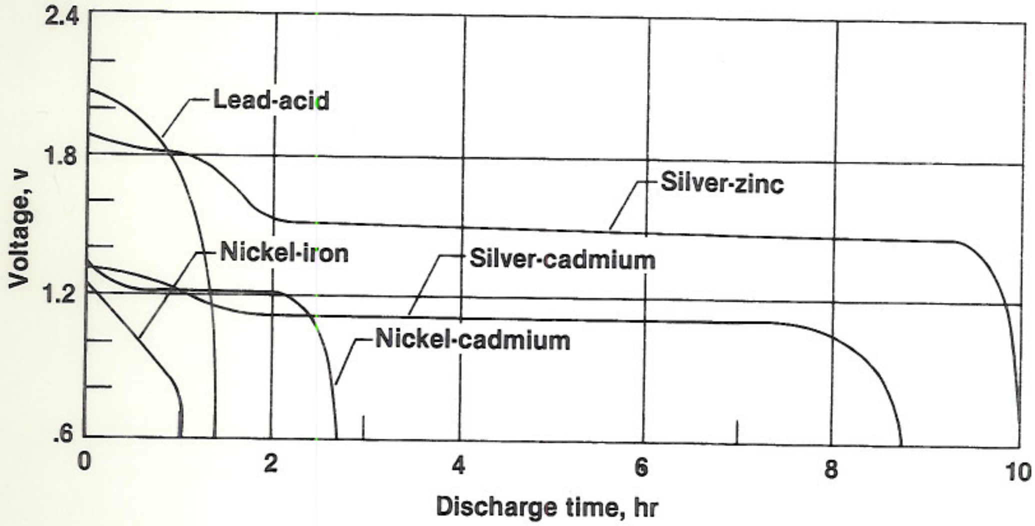


Figure 1. Typical discharge characteristics of various battery systems of equal weight when discharging under the same conditions (ref. 2).

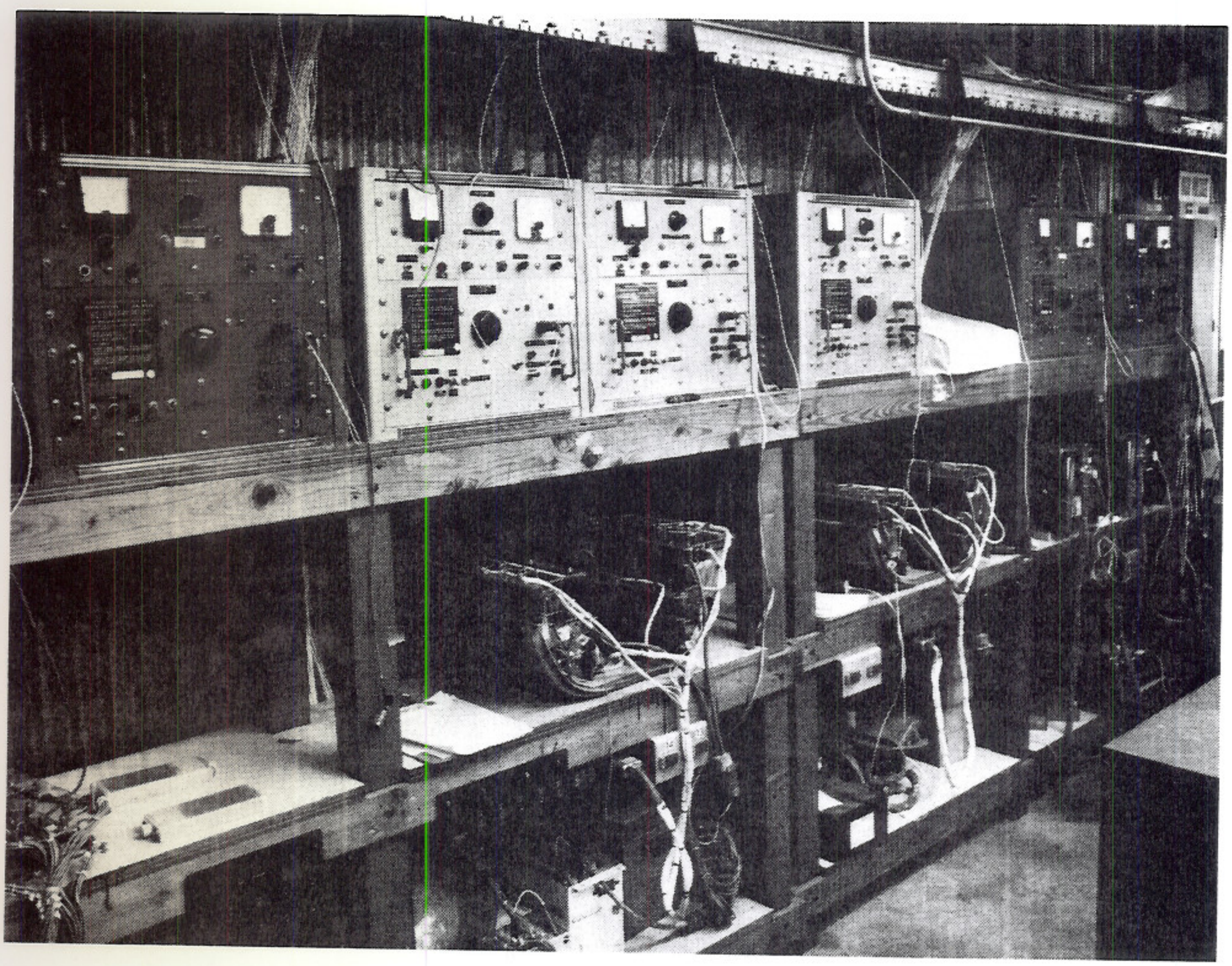


Figure 2. Method of obtaining cell readings from batteries.

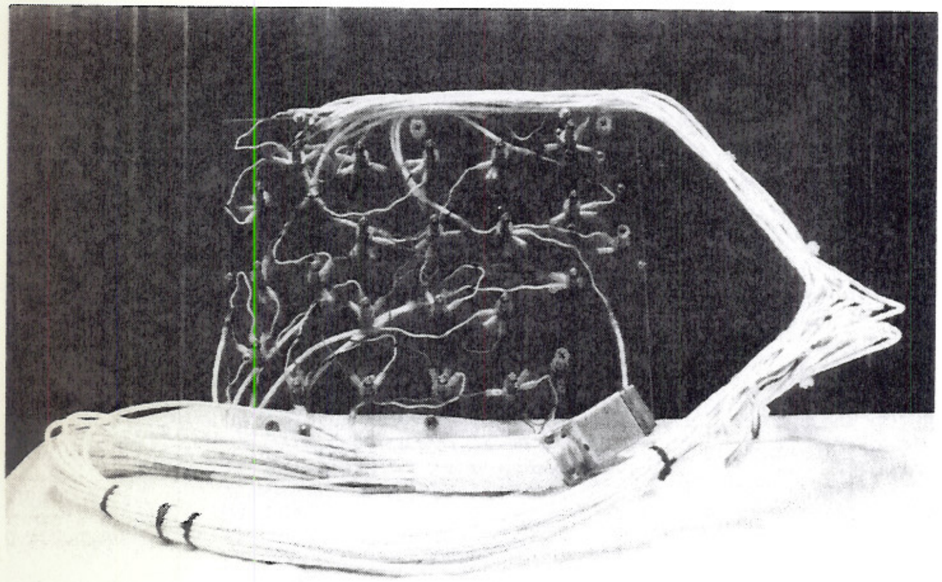


Figure 3. Typical cell monitoring plate which is attached to battery to obtain cell readings.

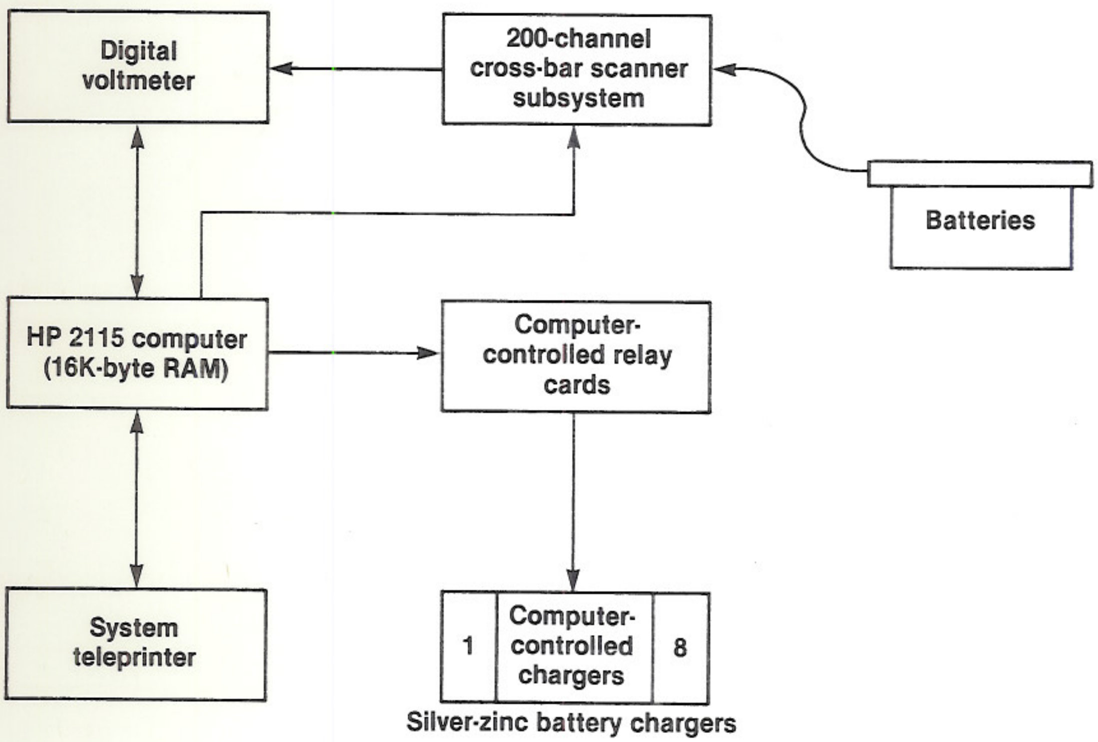


Figure 4. Original monitoring system (1970).

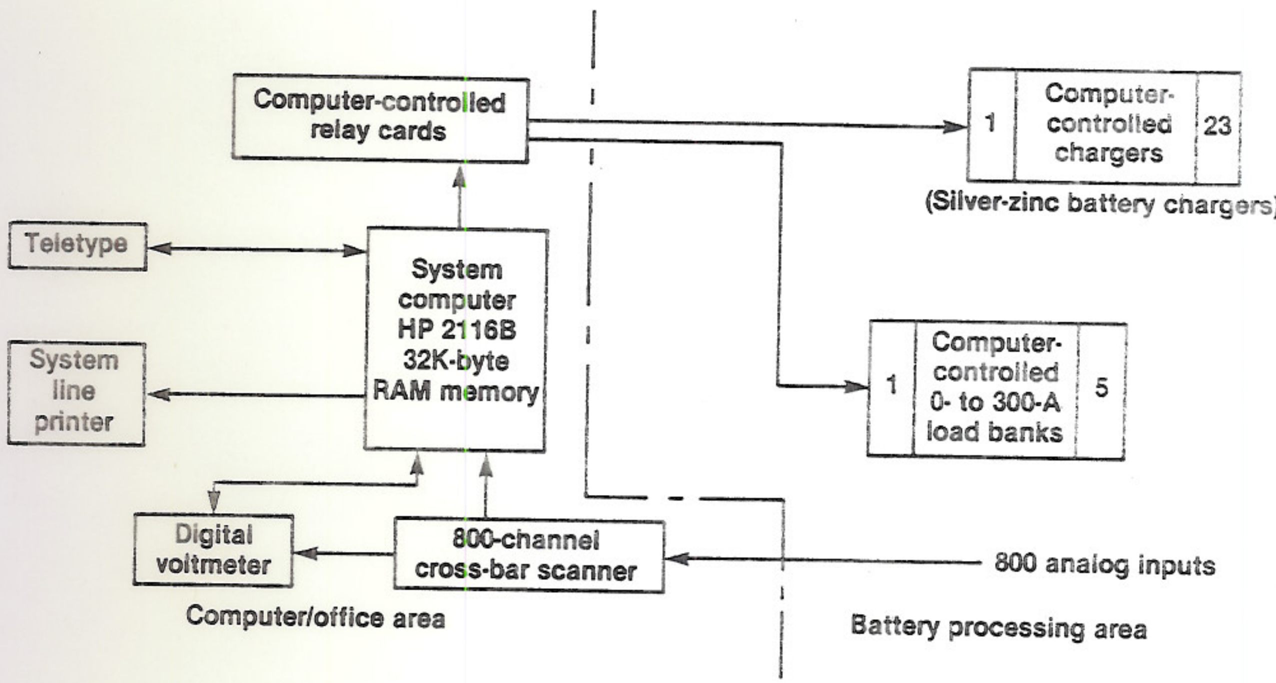
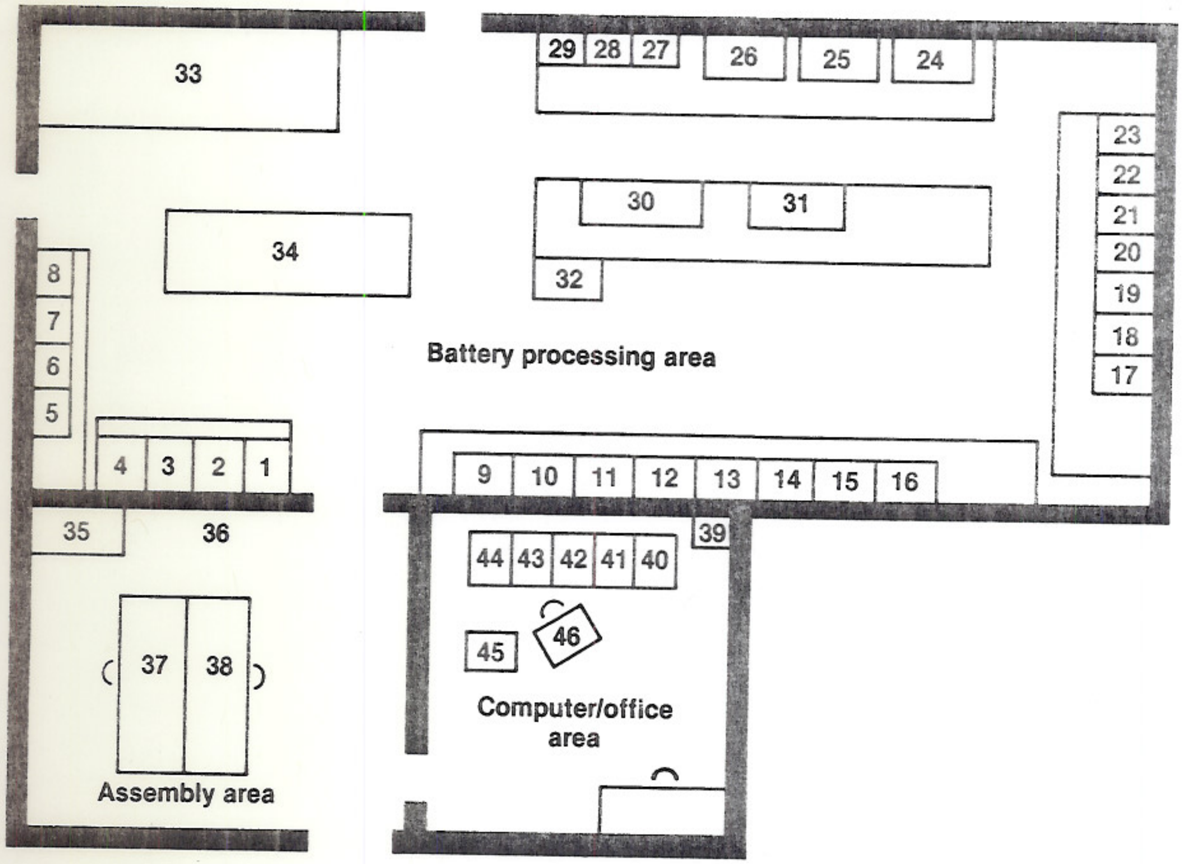


Figure 5. System expansion, 1973.



1-23	Silver-zinc battery chargers
24,25,30,31	Christie ReFlex nickel-cadmium chargers
27-29	Marathon nickel-cadmium charger/analyzers
33	Cold chamber
32	24-channnel temperature recorder
34	Work/storage bench
35	Wash area
36	Emergency eye bath
37-38	Work benches
39	Battery scanner interface cabinet
40	Disk unit
41	High-speed tape reader
42	Cross-bar scanner
43	Digital voltmeter and scanner
44	2116B computer
45	System line printer
46	System teleprinter

Figure 6. NASA Ames-Dryden Flight Research Battery Systems Laboratory (1973 expansion).

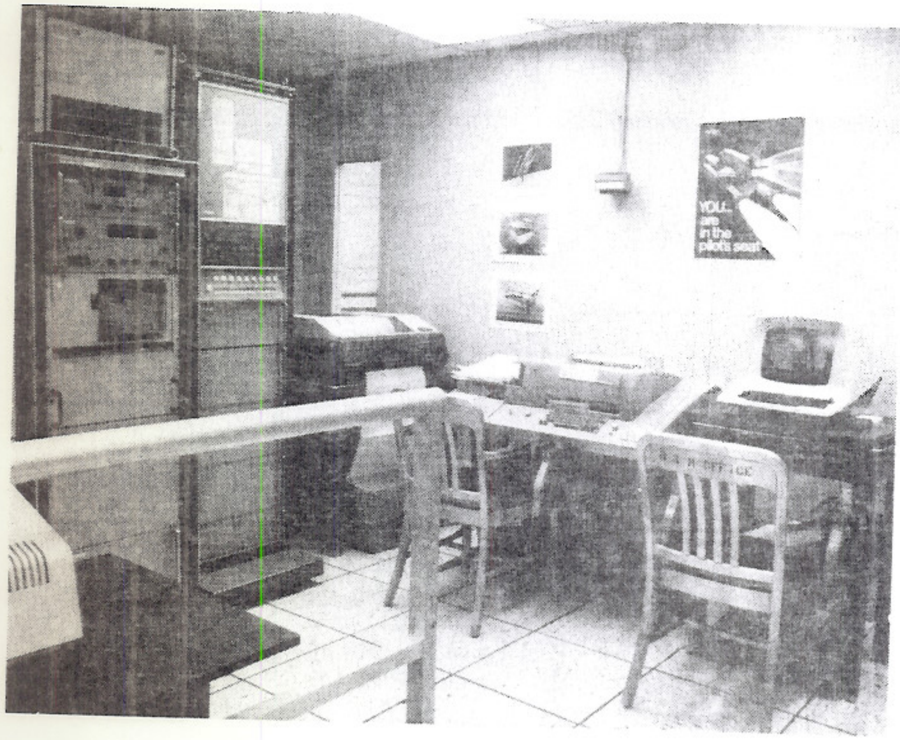


Figure 7. System expansion with HP 2116-based data-acquisition system.

Figure 8. Nickel-cadmium battery charging area with 1024-channel Neff analog input unit (far right).

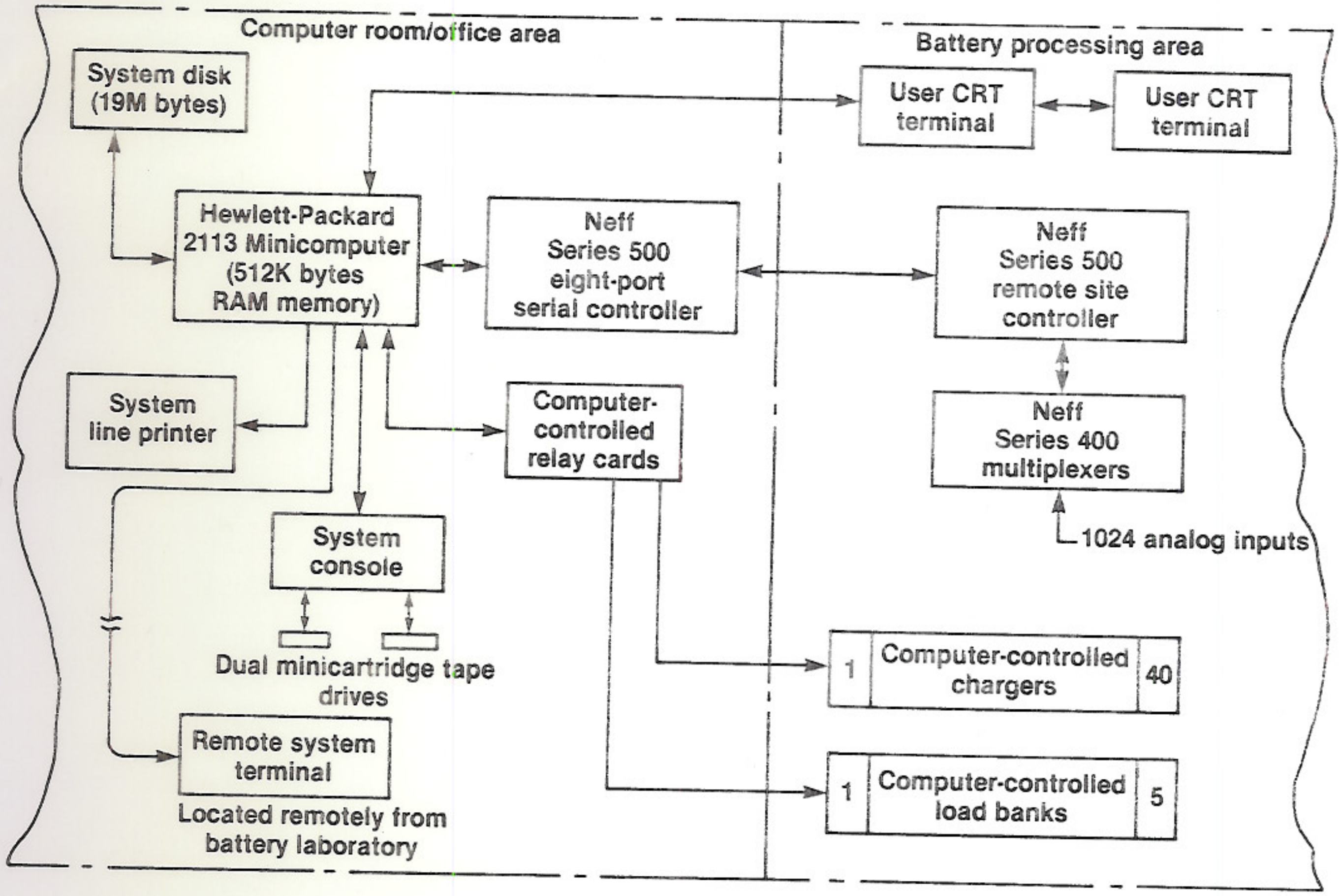
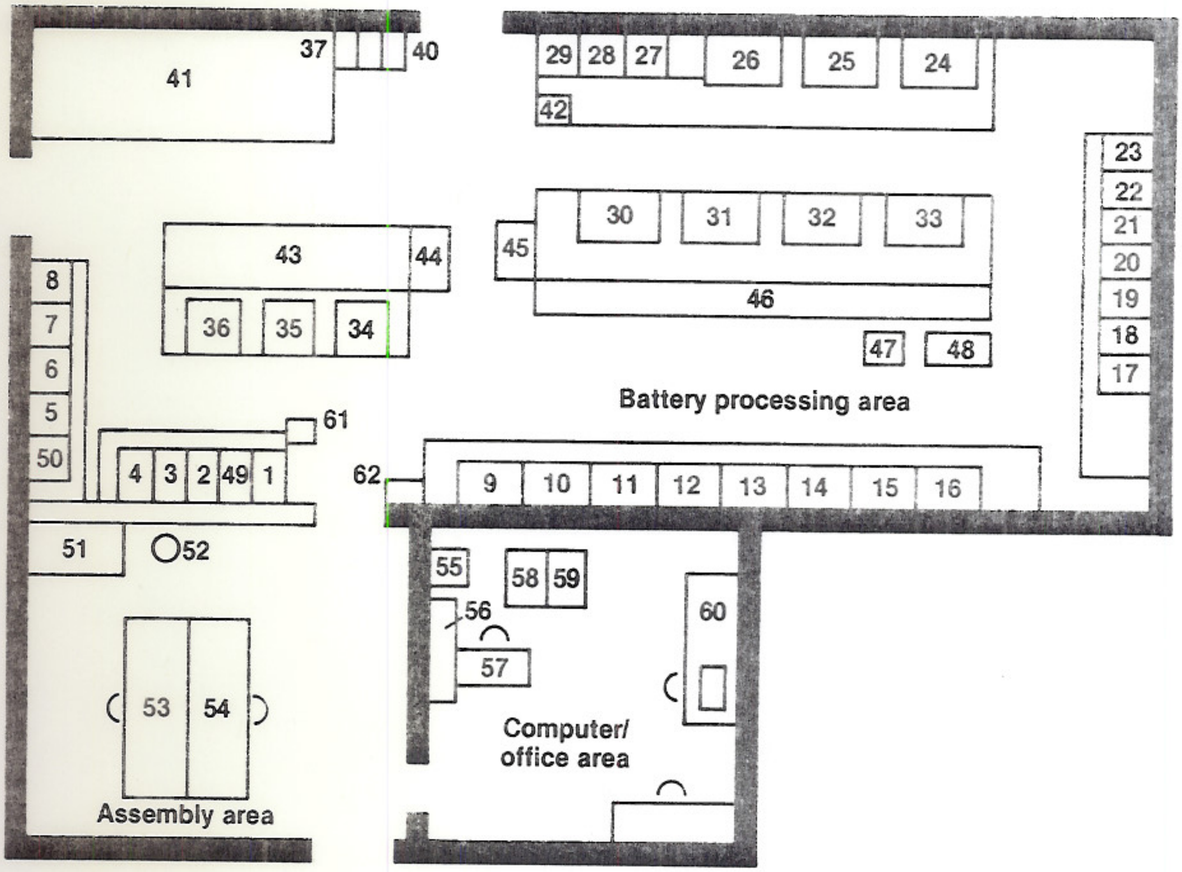


Figure 9. RTE computer-based battery monitoring system.

```
************** Hardware Failure Shutdown **************
*              At 5:12 PM Fri., 29 Oct., 1982          *
* The scanner subsystem has not responded to a scan    *
* request. There may be a failure of the subsystem. All *
* chargers have been shut down and removed from the    *
* scan cycle. All master load cart relays have been turned *
* off. See Operating Procedures for restoring the System *
* to its pre-failure condition.                         *
*********************************************************
```

Figure 10. Hardware failure notice produced when a major system component failure is detected.



1-23	Silver-zinc chargers	46	Work/storage bench
24-26	Nickel-cadmium ReFlex chargers	47	Rollaway load bank
27-29	Marathon nickel-cadmium chargers	48	Dual rollaway load bank
30-36	Nickel-cadmium ReFlex chargers	49	Stationary load bank
37-40	Additional monitoring stations	50	Stationary load bank
41	Cold chamber	51	Wash station
42	0- to 1-A constant-current charger/ tester	52	Emergency eye bath
43	Work/storage bench	53-54	Work benches
44	24-channel temperature recorder	55	RTE system line printer
45	Neff 1024-channel multiplexer unit	56	RTE work table
		57	RTE system console
		58	RTE computer system
		59	Neff controller interface unit
		60,61,62	Remote CRT user terminals

Figure 11. NASA Ames-Dryden Flight Research Battery Systems Laboratory (present configuration).

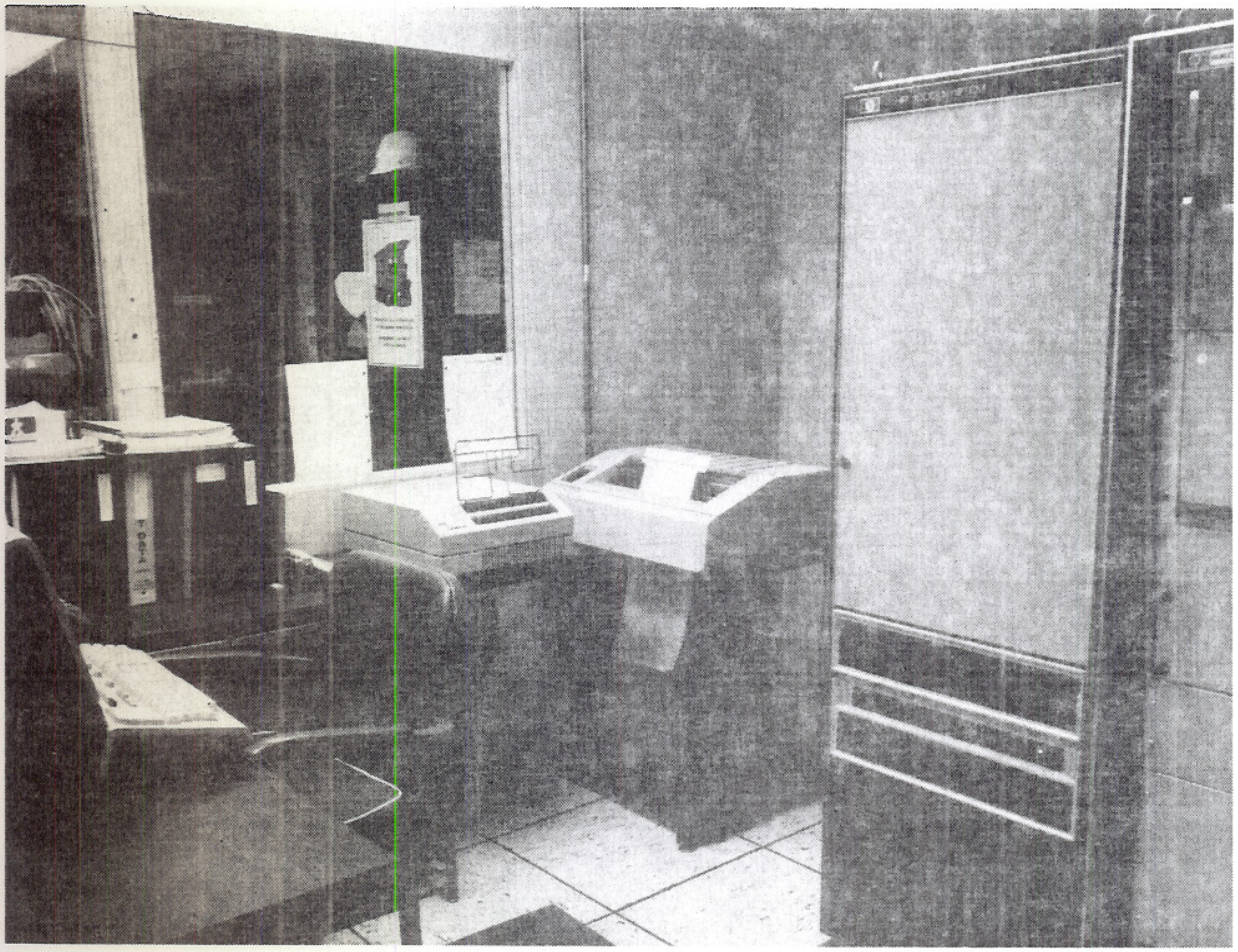


Figure 12. 1982 HP RTE computer system.

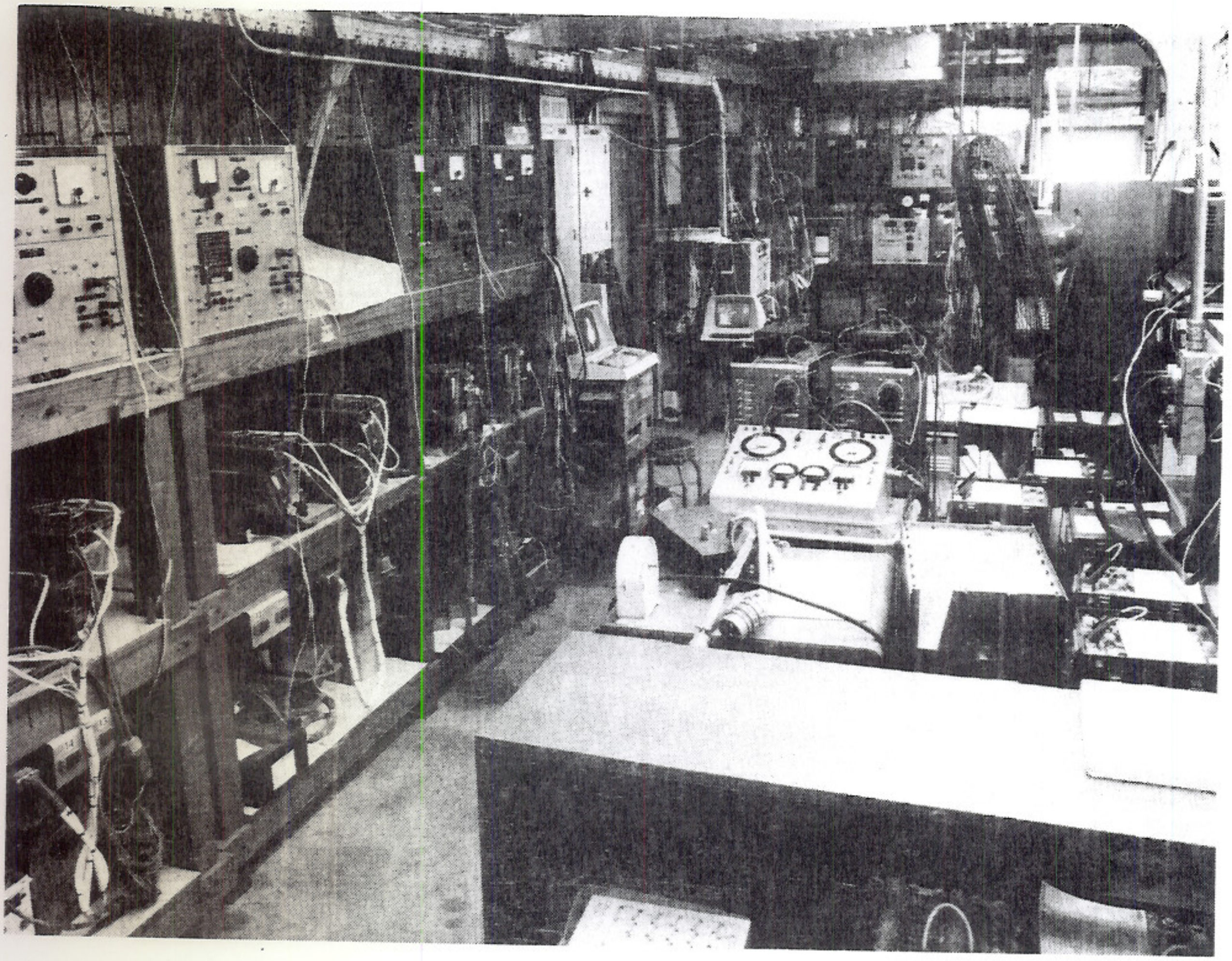


Figure 13. Silver-zinc battery charging area.

```
------ Charger number 2 ------------
------ Capacity test - begin test ----------
Date            : 11/04/82        Time              : 09:23:25
Bat. part no    : 1123            Serial number     : 01
Total volts     :  26.117         Shut down volts :    1.200
Amps/amp-hrs : 110.69/  9.701     Amp-hr rating     :  85.000
Load cart no    :    2            Elapsed time      : 00:00:00

Cell no.  1 = 1.383               Cell no. 13 = 1.382
Cell no.  2 = 1.376               Cell no. 14 = 1.375
Cell no.  3 = 1.382               Cell no. 15 = 1.372
Cell no.  4 = 1.368               Cell no. 16 = 1.375
Cell no.  5 = 1.368               Cell no. 17 = 1.360
Cell no.  6 = 1.375               Cell no. 18 = 1.362
Cell no.  7 = 1.369               Cell no. 19 = 1.379
Cell no.  8 = 1.380
Cell no.  9 = 1.376
Cell no. 10 = 1.381
Cell no. 11 = 1.380
Cell no. 12 = 1.375
```

Figure 14. Printout obtained during capacity test operations.

```
------ Charger number 4 ------------
------ Operator requested scan ----------
Date            : 11/05/82        Time              : 09:45:46
Bat. part no    : 7682            Serial number     : 1
Total volts     :  35.246         Shut down volts:    2.050
Amps/amp-hrs:    0.00/  16.167    Amp-hr rating     :  58.000

Cell no.  1 = 1.856               Cell no. 13 = 1.857
Cell no.  2 = 1.854               Cell no. 14 = 1.854
Cell no.  3 = 1.858               Cell no. 15 = 1.855
Cell no.  4 = 1.859               Cell no. 16 = 1.854
Cell no.  5 = 1.851               Cell no. 17 = 1.852
Cell no.  6 = 1.855               Cell no. 18 = 1.854
Cell no.  7 = 1.851               Cell no. 19 = 1.856
Cell no.  8 = 1.854
Cell no.  9 = 1.858
Cell no. 10 = 1.855
Cell no. 11 = 1.856
Cell no. 12 = 1.856
```

Figure 15. Printout produced by an operator-requested scan.

Charger status. Date: 11/05/82 Time: 13:06:15 (C = Charging)

Charger no. 1	Charger no. 21
Charger no. 2	Charger no. 22 On scan
Charger no. 3 On scan	Charger no. 23
Charger no. 4 On scan C	Charger no. 24
Charger no. 5	Charger no. 25
Charger no. 6	Charger no. 26
Charger no. 7	Charger no. 27
Charger no. 8	Charger no. 28
Charger no. 9 On scan C	Charger no. 29
Charger no. 10 On scan	Charger no. 30
Charger no. 11	Charger no. 31
Charger no. 12 On scan	Charger no. 32
Charger no. 13 On scan	Charger no. 33
Charger no. 14	Charger no. 34
Charger no. 15	Charger no. 35
Charger no. 16	Charger no. 36
Charger no. 17	Charger no. 37
Charger no. 18	Charger no. 38
Charger no. 19	Charger no. 39
Charger no. 20	Charger no. 40

Figure 16. Charger status check printout.

------ Charger number 22 ------------

------ Abnormal shut-down -----------

Date	: 11/01/82	Time	: 11:43:26
Bat. part no	: 999	Serial number	: 10
Total volts	: 42.830	Shut down volts:	2.050
Amps/amp-hrs:	.15/ .035	Amp-hr rating	: 20.000

Cell no. 1 = 1.875	Cell no. 13 = 1.874
Cell no. 2 = 1.889	Cell no. 14 = 1.879
Cell no. 3 = 1.872	Cell no. 15 = 1.888
Cell no. 4 = 1.906	Cell no. 16 = 1.891
Cell no. 5 = 1.878	Cell no. 17 = 1.898
Cell no. 6 = 1.887	Cell no. 18 = 1.878
Cell no. 7 = 1.894	Cell no. 19 = 1.898
Cell no. 8 = 1.889	Cell no. 20 = 1.907
Cell no. 9 = 1.888	Cell no. 21 = 1.877
Cell no. 10 = 3.200 *	Cell no. 22 = 1.881
Cell no. 11 = 1.880	
Cell no. 12 = 1.902	

Figure 17. Typical printout of abnormal cell reading caused by a faulty contact.

```
------ Charger number 22 -----------
------ Low cell shut-down ------------
Date          : 11/03/82          Time             : 14:46:15
Bat. part no  : 999               Serial number    : 10
Total volts   :    -.020          Shut down volts:   2.050
Amps/amp-hrs:    0.00/ 2.027      Amp-hr rating    :  20.000

Cell no.  1 =   0.000 *           Cell no. 13 =  -.001 *
Cell no.  2 =  -.001 *            Cell no. 14 =  -.001 *
Cell no.  3 =  -.001 *            Cell no. 15 =  -.001 *
Cell no.  4 =  -.001 *            Cell no. 16 =  -.001 *
Cell no.  5 =  -.001 *            Cell no. 17 =  -.001 *
Cell no.  6 =  -.001 *            Cell no. 18 =  -.000 *
Cell no.  7 =  -.001 *            Cell no. 19 =  -.001 *
Cell no.  8 =  -.001 *            Cell no. 20 =  -.001 *
Cell no.  9 =  -.001 *            Cell no. 21 =  -.001 *
Cell no. 10 =  -.000 *            Cell no. 22 =  -.001 *
Cell no. 11 =  -.001 *
Cell no. 12 =  -.001 *
```

Figure 18. Typical printout of abnormal cell reading caused by the battery's not being connected to the system.

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16. Abstract

This document discusses the development of the Dryden Flight Research Facility Battery Systems Laboratory. This laboratory processes nickel-cadmium and silver-zinc batteries used in the various flight research vehicles flown at the Dryden facility. Described is the evolvement of the original manually operated lead-acid battery facility to the present computerized laboratory. Described also are the equipment and present capabilities of the laboratory, which can process both sealed and wet vented cells that range in capacity from 0.5 to 200 A-hr.

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